PARENTAL CARE IN *NOTONOMUS* CHAUDOIR (COLEOPTERA: CARABIDAE: PTEROSTICHINAE)

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Abstract
Brood care by females of four *Notonomus* species is described. This is the first description of such behaviour in Australian species of Carabidae and is an additional record to the few carabid species worldwide known to exhibit parental care.

Introduction

Parental care of eggs or early immature stages is known in many groups of insects and other arthropods (Tallamy 1984). In addition to the social insects, Hinton (1981) listed over 170 species of sub-social insects known to protect or care for their young. The list contained only 3 species of Carabidae but Hinton forecast that this number would increase as our knowledge of this family improved. Thiele (1977) was able to list 15 species of carabids that exhibited brood care, 14 Pterostichinae and 1 Harpalinae, with none from Australia. Although some Australian Pterostichinae care for eggs or young they have not previously been recorded in the literature (Moore, Weir and Pyke 1987). It is of interest that while parental care has evolved independently in many of the insect orders (Tallamy 1984; Hinton 1981), it has arisen in the Carabidae only in the subfamilies Pterostichinae and Harpalinae.

Notonomus Chaudoir is the largest Australian genus within the Pterostichinae and the 4 species referred to in this paper, plus *N. chalybeus* (Dejean) make up the "*chalybeus*-group" (Sloane 1913). This paper records brood care by adult females of *Notonomus* (*N. gravis* (Chaudoir), *N. phillipi* (Newman), *N. molestus* (Chaudoir) and *N. kershawi* Sloane) in Victoria and discusses the relevance of this behaviour when interpreting pitfall trapping data. The adults are flightless and are generalist feeders that usually shelter below the soil surface or under some cover during the day and are active above the soil surface at night.

Methods

Field collections of the 4 species of *Notonomus* were made in their respective ranges and habitats; western plains to Melbourne (*N. gravis*), Healesville and Otway Ranges (*N. phillipi*), Grampians Ranges (*N. molestus*) and central Otway Ranges (*N. kershawi*). Direct searching by overturning rocks and logs revealed sheltering adult carabids and, at appropriate times, adult female carabids in chambers with eggs and larvae.

N. gravis was also collected from a grid of 50 pitfall traps within a

Table 1. Numbers of male and female *N. gravis* captured in pitfall traps at La Trobe University during December 1982.

	MALE		FEMALE		TOTAL	
	Teneral	Old	Teneral	Old	Teneral	Old
Dec 1-15	30	28	33	14	63	42
Dec 16-31	111	107	128	32	239	139
Total	141	135	161	46	302	181

fenced reserve on the La Trobe University campus, Victoria. Each trap consisted of a plastic cup, 80 mm deep and 60 mm diameter, with small drainage holes in the base. Traps were checked 6-7 days per week over spring and summer and 1-3 times per week in autumn and winter, from February 1978 to September 1979 and from September 1982 to October 1983. All beetles were returned to the laboratory where their sex and maturity were noted. Individuals were categorized as either, (1) teneral male, (2) teneral female, (3) old (non-teneral) male, or (4) old (non-teneral) female. (Teneral beetles were identified by the soft elytra, which were easily deformed when pressed). Field collected adults of *N. gravis* and *N. phillipi* were maintained in the laboratory to allow observations to be made on oviposition (brood) chamber construction, oviposition and brood care. Carabids were maintained in clear plastic containers (265 x 195 x 100 mm) half filled with damp peat-moss and fed moistened pellets of commercial dog food (LUV).

Results

Field observations revealed that adult females of all species constructed oviposition chambers in soil. Chambers were expansions at the end of a tunnel, just large enough to contain the adult female together with freshly laid eggs or with eggs and first instar larvae. The observed oviposition periods for each species were: *N. gravis*, May; *N. phillipi*, April; *N. kershawi*, April; *N. molestus*, October.

In the laboratory, adult females of both *N. gravis* and *N. phillipi* exhibited the maternal behaviour described by Brandmayr and Brandmayr (1979) as "Brutfursorge", that is, activities conducted before and after egg-laying which favour survival of larvae. Prior to oviposition they excavated chambers in the peat moss, large enough to accommodate one adult and eggs. Batches of 20-30 eggs were laid by each female during May-June (*N. gravis*) and March-April (*N. phillipi*). The adult female remained with the eggs and first instars until all eggs had hatched, a total duration of at least 4 weeks in each species. The adult female did not feed during this period.

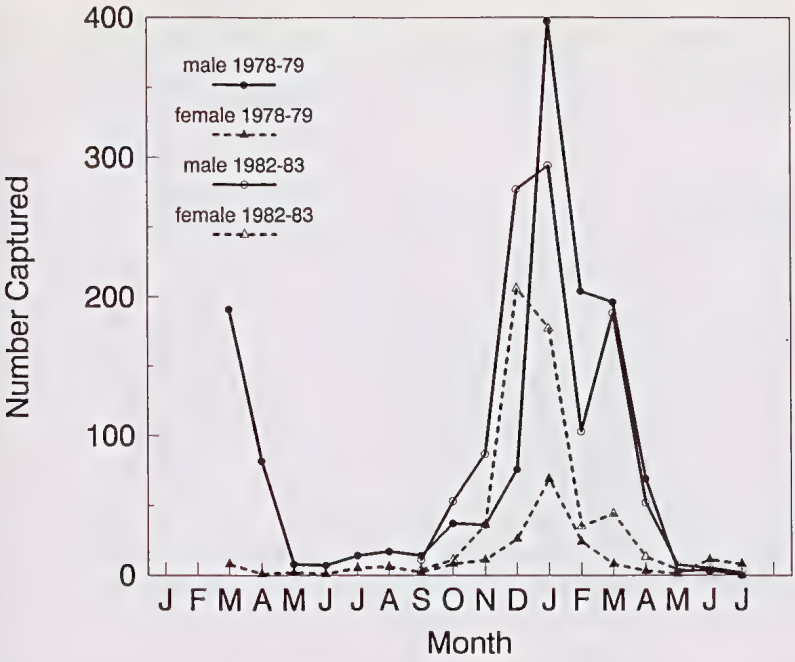

Fig. 1. Numbers of male and female *N. gravis* captured in a grid of 50 pitfall traps at La Trobe University, Bundoora, in 1978-79 and 1982-83.

Within each batch first instar larvae emerged no more than 2 days apart, indicating synchronisation of this stage. In the laboratory, when adult females were removed from brood chambers the eggs left behind often developed lethal fungal infections.

Numbers of *N. gravis* captured in pitfall traps were highest at the time of adult emergence in December-January and lowest between May and September (Fig. 1). The sex ratio varied throughout the year with males almost always predominating. Sex ratios for teneral and old beetles were calculated separately and the results for one month (December 1982) are presented in Table 1. The results for December were chosen as the population then consisted of two easily identifiable components: newly emerged teneral beetles and old (mostly one year old) beetles. At that time of year activities such as mating, oviposition and brood chamber construction were not complicating the activity pattern of *N. gravis* and equal densities of males and females could be expected. There was a significant difference ($p < 0.05$, $t = 4.90$, 3 d.f.) between the ratios for teneral and old beetles, with the ratio being 1.00: 1.14, male: female ($n = 302$) for teneral individuals but 2.93: 1.00 ($n = 181$) for old beetles. It is, therefore, clear that many old females

were removed from the portion of the population that was active on the surface and, if pitfall trapping data but no other biological information were available, a variety of interpretations (activity, mortality, migration) of this trend could be made.

Discussion

Maternal care was observed in all 4 species, but as these are the only *Notonomus* species to have been the subject of biological studies, it is quite likely that other members of this genus have similar behaviour.

Parental care provides benefits for offspring by improving survival chances but may be costly for the parent insects, usually the females (Tallamy 1984). It is probable that female *Notonomus* protect their eggs from either predators (including other *Notonomus*) or fungal attack. Brood caring Carabidae are mostly montane species and this behaviour has been considered an adaptation to cooler climates (Brandmayr and Brandmayr 1979; Thiele 1977). *Notonomus* displays similar behaviour and is mostly restricted to the mountains of eastern Australia but some of the habitats are not always cool. *N. gravis* for example, inhabits the western (volcanic) plains of Victoria where temperatures in excess of 40 °C are regularly recorded.

The brood care behaviour effectively removed adult females from the surface and so from potential capture in pitfall traps. The cost for female *N. gravis* is reduced opportunity for normal feeding activity on the soil surface for over a month and probably increased mortality compared to males. Equal numbers of male and female *N. gravis* emerged as teneral adults but fewer females were present after one year (Table 1). Activity of females, as measured by pitfall trapping, is less than that of males except during the period of first adult emergence (December) and immediately following first instar emergence in May-June (Fig. 1). After one month without food, female *N. gravis* are forced to replenish diminished reserves during May-June, which may cause a higher rate of mortality and explain why fewer "old" females were captured later in the year.

If parental care occurs in other carabid species as suggested, then caution should be taken in the interpretation of pitfall trapping data. Pitfall traps measure activity in addition to density (den Boer 1986) and if either or both sexes have behavioural patterns that modify activity, an incorrect estimate of abundance and sex ratio may be made. Particular care needs to be taken in Australia where little is known of the biology of the carabid fauna. As exemplified by *N. gravis*, the dramatic change in sex-ratio between teneral and mature beetles clearly reflects female inactivity resulting from brooding behaviour with consequent increased mortality of female beetles later in the year.

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